The Odderon and spin-dependence of elastic proton-proton scattering.

T.L.Trueman, BNL

April 29, 1998

Spin-dependence of high energy proton-proton elastic scattering provides a new and sensitive tool to search for the Odderon. The reason for this is that the asymptotic phase of the scattering amplitude is closely tied to the C of the exchanged system; thus, in leading order, if the Pomeron and Odderon have the same symptotic behaviour, up to logs, then they are out of phase by 90°. Spin dependent asymmetries depend on various real and imaginary parts of products of amplitudes and so the Odderon can dominate some asymmetries to which the Pomeron cannot contribute: thus, for example the purely hadronic piece of A_N, (Fig.1) which vanishes as $t \to 0$, is zero for purely $C = +1$ exchange; a deviation from zero would be a strong indicator that a Pomeron is present. (If the two parts differ in their asymptotic behaviour by powers of $\ln(s/s_0)$ there will be $\pi/\ln(s/s_0)$ corrections to this and most of the other comments made in this talk. For this reason, it will be important to measure the asymmetries over as wide a range of s as possible.) At the same time, in the CNI region the purely $C = +1$ spin-flip Pomeron piece is what stands in the way of using this process as a polarimeter. (Fig.2,3,4). The basic properties of the Odderon and the phase argument are given in Fig. 4 and 5.

Fig.6 lists all the measurable asymmetries using polarized beams, without final polarization measurements. A_{NN} gives a CNI-type peak if the Odderon contributes to the double spin-flip amplitude ϕ_2^O (Fig.7). If the Pomeron also couples to ϕ_2^P there will be a purely hadronic (non-enhanced) piece which will have a distinctly different shape. It may very well be possible to extract both of these pieces from measuring A_{NN} if they are not too small (Fig.8). Similar arguments can be applied to the other asymmetries. A_{SS} is basically the same as A_{NN} at small t, so additional information requires longitudinally polarized protons as well. If this is possible then complete information about the asymptotic amplitudes ϕ_-, ϕ_2 and ϕ_5, both the $C = +1$ and $C = -1$ pieces, should be attainable. (Fig.9) The last column shows the expected dominant contributions to the purely hadronic piece of the asymmetry, based on the minimum number of Odderons and spin-flips in the combination. Of course, this will need to be checked.

A final comment: in order to use CNI in elastic $p - p$ scattering for polarimetry it is necessary to know the ratio ϕ_5^P/ϕ_+^P; see A_N in the Table in Fig.9. If the expectation for the dominant amplitudes for each of the asymmetries is valid, and if A_{SS} or A_{LL} is large enough to make a reliable measurement, then one can use, in addition, the measurement (or limit) on A_{SL} to determine (or bound) this ratio, *independent of P*. Thus elastic $p - p$ scattering may turn out to be useful as a self-calibrating polarimeter for RHIC.

Workshop on Spin Dependence of Elastic proton-proton scattering at RHIC Energy
(Summer 1997 – sponsored by RIKEN BNL Research Center)

Leader

Buttimore

Soffer

Kopeliovich

Trueman

+ others

Instigated by problem of Polarimetry at RHIC: CNI

Hadronic Spin-flip Contribution to AN

Parametrize hadronic spin-flip:

$$\phi_5^h = \tau\sqrt{-t/m^2}(\phi_1^h + \phi_3^h)/2$$

For s>>m², t<<m²: ϕ_2^h, ϕ_4^h negligible

$$A_N\frac{d\sigma}{dt} = \frac{\alpha\sigma_{tot}}{2m\sqrt{-t}}\{(\mu-1) - 2Re(\tau)\} + 2Im(\tau)\frac{\sqrt{-t}}{m}\frac{d\sigma}{dt}$$

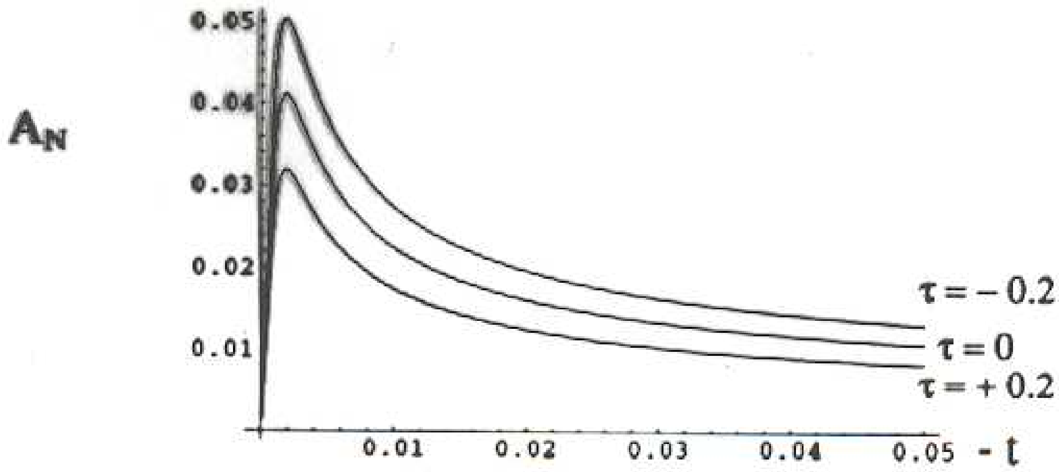
Define τ^* as best limit on Re(τ):

$$|Re(\tau)| \leq \tau^*$$

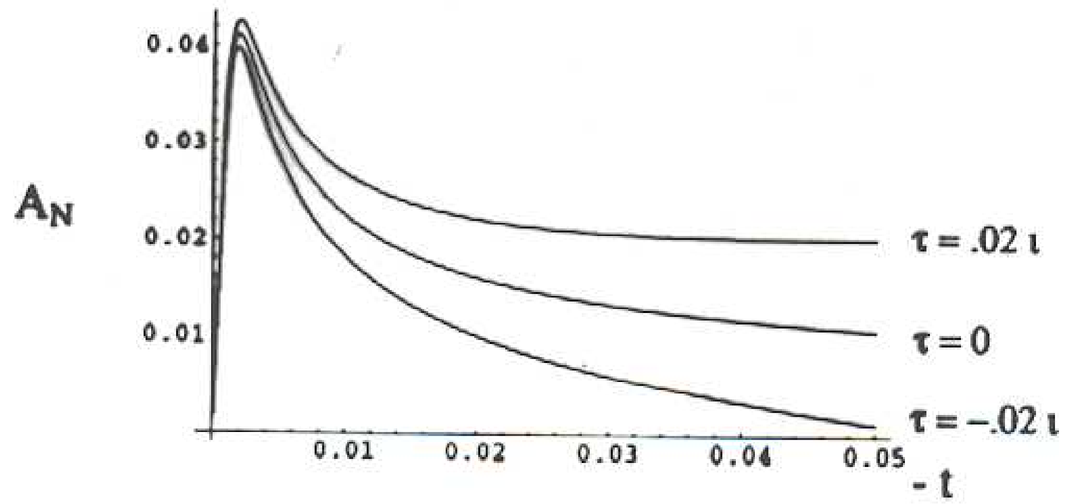
Precision of measurement of P limited by:

$$\frac{\Delta P}{P} \geq \frac{2\tau^*}{(\mu-1)}.$$

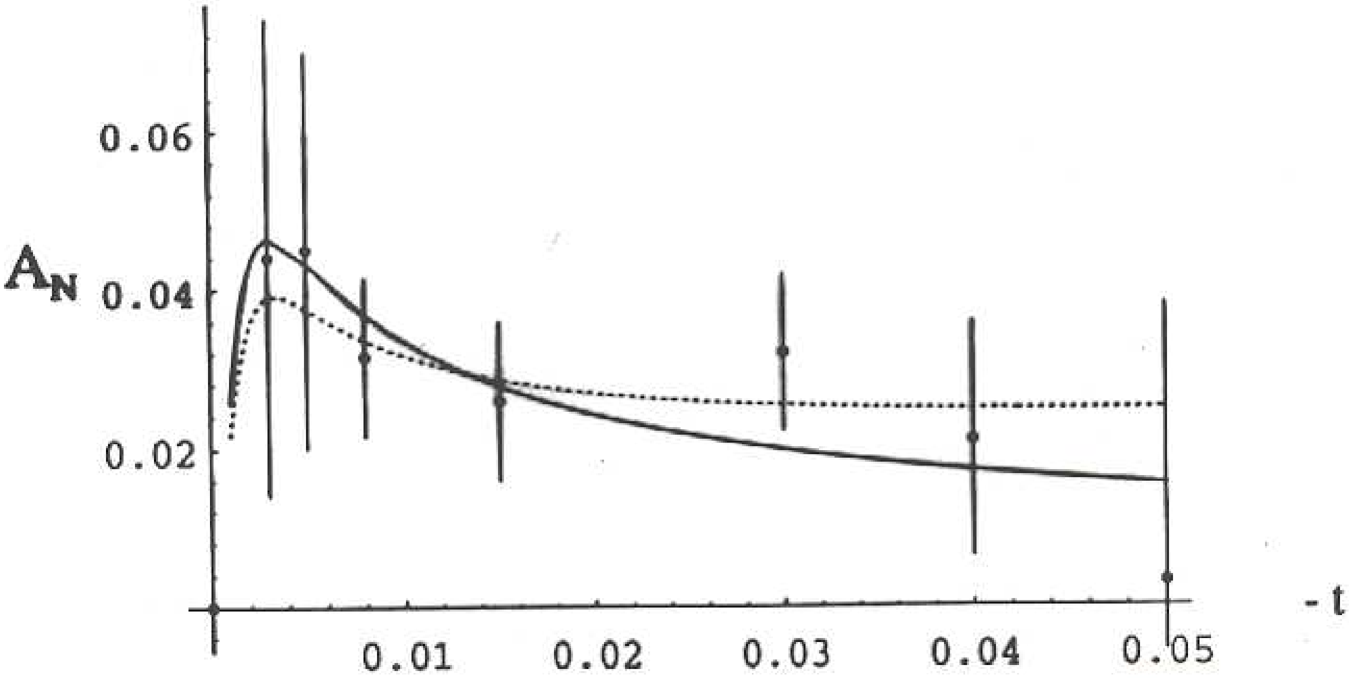
Analyzing power at RHIC for various in-phase spin-flip amplitudes



Analyzing power for various out-of-phase spin-flip amplitudes



Best fits to 704 data with and without $\mathrm{Im}(\tau) = 0$



$\tau = 0.0 \pm 0.15$

$\tau = 0.2 + 0.03\,\mathrm{I} \pm (0.3 + 0.01\,i)$

The Odderon

the $C = -1$ partner of the Pomeron

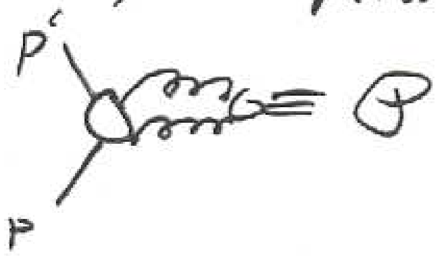
- arbitrary relative phase of ϕ_1 and ϕ_5
- coupling to $\phi_1 + \phi_3$ gives

$$\sigma_{pp} - \sigma_{\bar{p}p} \not\to 0 \quad \text{as } s \to \infty$$

and possible large corrections to

ρ and $\bar{\rho}$

originated with Lukaszuk + Nicolescu (1973), Leader et al, Lipatov et al



- limit on coupling to $(\phi_1 + \phi_3)$ (Block et al) $< 2\%$. Nothing known of coupling to ϕ_2, ϕ_5

Phase of scattering amplitudes

Theorem of Van Hove - based on real analyticity of scattering amplitudes

If $\quad f(-s) = \eta f(s) \quad , \eta = \pm 1$

and $\quad f(s) \sim s^{\alpha} \quad$ as $s \to \infty$

then $\quad$ phase of f is $e^{i\pi\alpha/2}$, $\eta = +1$

$$i e^{i\pi\alpha/2}, \quad \eta = -1$$

so spinless amp. with $C=+1$ Pomeron is pure imaginary (with calculable $1/\lg s$ real part)
(importance of measuring s-dependence)

For $p\bar{p}$ need C and crossing:

$$M_{\lambda_3 \lambda_4 \lambda_1 \lambda_2}(s,t) = \eta_C \overline{M}_{\lambda_3 \lambda_4 \lambda_1 \lambda_2}(s,t)$$

$$\overline{M}_{\lambda_3 \lambda_4 \lambda_1 \lambda_2}(s,t) = M_{\lambda_3 -\lambda_2, \lambda_1 -\lambda_4}(-s,t)$$

so $\quad \phi_1 + \phi_3 = \phi_+ , \ \phi_2 , \ \phi_5 \quad$ imaginary

$\phi_1 - \phi_3 = \phi_- \quad$ real) as $s \to \infty$

for $C=+1$

Measurable quantities

$$\sigma_{tot} = \frac{4\pi}{s} \, \mathrm{Im}\left(\phi_1(s,0) + \phi_3(s,0) \right)$$

$$\Delta\sigma_T = -\frac{8\pi}{s} \, \mathrm{Im}\, \phi_2(s,0)$$

$$\frac{d\sigma}{dt} = \frac{2\pi}{s^2}\left(|\phi_1|^2 + |\phi_2|^2 + |\phi_3|^2 + |\phi_4|^2 + 4|\phi_5|^2 \right)$$

$$\rightarrow \quad A_N \frac{d\sigma}{dt} = -\frac{4\pi}{s^2} \, \mathrm{Im}\left(\phi_5^* (\phi_1 + \phi_2 + \phi_3 - \phi_4) \right)$$

$$A_{NN} \frac{d\sigma}{dt} = \frac{4\pi}{s^2} \left\{ 2|\phi_5|^2 + \mathrm{Re}(\phi_1^* \phi_2 - \phi_3^* \phi_4) \right\}$$

$$A_{LL} \frac{d\sigma}{dt} = \frac{2\pi}{s^2} \left\{ |\phi_1|^2 + |\phi_2|^2 - |\phi_3|^2 - |\phi_4|^2 \right\}$$

$$= \frac{2\pi}{s^2} \left\{ \mathrm{Re}\, \phi_+^* \phi_- + |\phi_2|^2 - |\phi_4|^2 \right\}$$

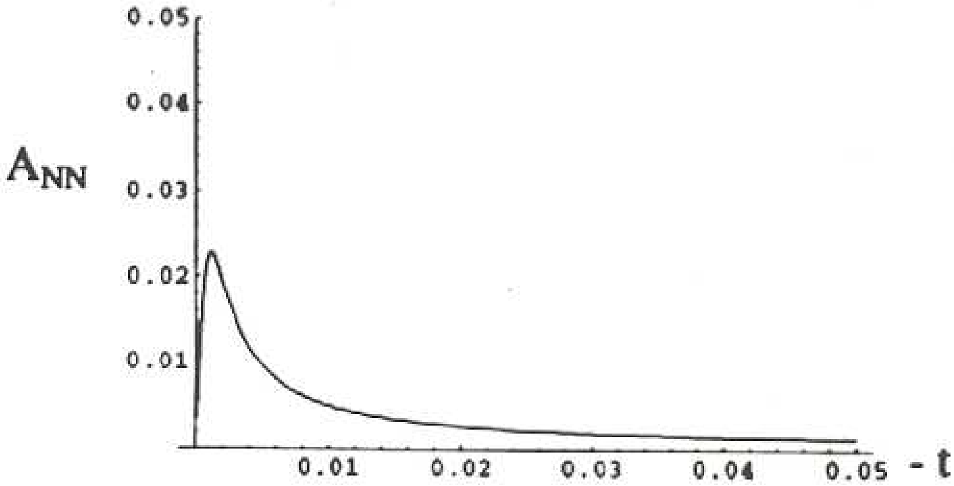
$$A_{SS} \frac{d\sigma}{dt} = \frac{4\pi}{s^2} \, \mathrm{Re}\left(\phi_1^* \phi_2 + \phi_3^* \phi_4 \right)$$

$$A_{SL} \frac{d\sigma}{dt} = \frac{4\pi}{s^2} \, \mathrm{Re}\left(\phi_5^* (\phi_1 + \phi_2 - \phi_3 + \phi_4) \right)$$

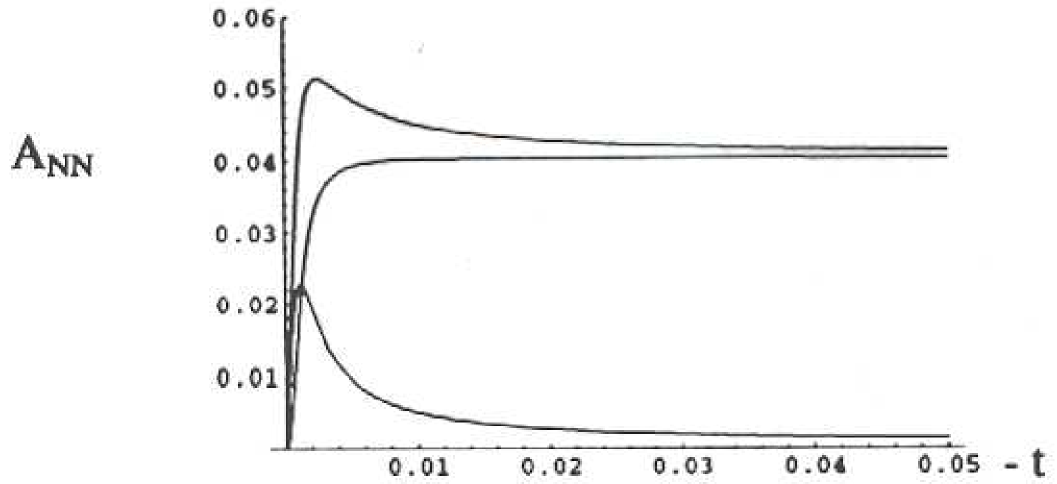
$$\Delta\sigma_L = \frac{4\pi}{s} \, \mathrm{Im}\left(\phi_1 - \phi_3 \right)$$

cf. e.g. Buttimore, Gotsman + Leader (1978)

Enhanced A_{NN} for $r_2 = .02$ I,
where $\phi_2 = r_2\,\phi_1$.



Comparison of A_{NN} for various values of r_2:
.02 I (lower), .02 (middle), .02 + .02 I (upper).



Asymmetry	CNI Enhanced	Dominant? (ΔS, # Odd.)
A_N	ϕ_+^P, ϕ_5^P	$\phi_+^P \phi_5^O$ (0,1)
A_{NN}	ϕ_2^O	$\phi_+^P \phi_2^P$ (2,0)
A_{SS}	ϕ_2^O	$\phi_+^P \phi_2^P$ (2,0)
A_{SL}	ϕ_-^P	$\phi_5^P \phi_-^O$ (1,1)
		or $\phi_5^P \phi_2^P$ (3,0)
A_{LL}	ϕ_-^P	$\phi_+^P \phi_-^O$ (0,1)

and

σ_{tot} : ϕ_+^P

$\Delta\sigma_T$: ϕ_2^P

$\Delta\sigma_L$: ϕ_-^O